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(54) NONLINEAR OPTICAL CRYSTAL

(57) There is provided a nonlinear optical crystal which is presented by the formula: $K_2Al_2B_2O_7$. This nonlinear optical crystal is a vacuum ultraviolet light generating nonlinear optical crystal which is easy to grow and of high practical use. There are also provided a wavelength conversion method using this crystal, and an element and a wavelength conversion apparatus for use in the method.

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Description

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention relates to a nonlinear optical crystal. More specifically, the invention relates to a novel nonlinear optical crystal useful as a wavelength conversion crystal for generating vacuum ultraviolet light or the like, and a wavelength conversion method using the wavelength conversion crystal, as well as an element and a wavelength conversion apparatus for use in the method.

BACKGROUND ART

[0002] With the development of laser technology, it has become an importance subject to realize solid-state lasers having performance which allows for the applications of laser technology. One such subject is to put into practice all solid-state vacuum ultraviolet laser light sources of shorter wavelength.

[0003] To realize an all solid-state vacuum ultraviolet laser light source of short wavelength, there is a need for a nonlinear optical crystal which has a double refraction index of about 0.07 and an absorption edge which lies in the range of short wavelengths of 150-160 nm. As prior art nonlinear optical crystals which satisfy these characteristics, the following ones have been known:

$Sr_2Be_2B_2O_7$ (SBBO),
$KBe_2BO_3F_2$ (KBBF).

[0004] These publicly known prior art SBBO and KBBF, however, have the large problem that both crystals are difficult to obtain, because they are extremely difficult to grow.

SUMMARY OF THE INVENTION

[0005] Therefore, the invention provides a nonlinear optical crystal. More specifically, the invention provides a novel nonlinear optical crystal for all solid-state generation of vacuum ultraviolet light, which has the required characteristics and is easy to obtain through crystal growth instead of the prior art SBBO and KBBF, and a wavelength conversion method using such novel nonlinear optical crystal, as well as an element and a wavelength conversion apparatus for use in the method.

[0006] To solve the above-described subject, the invention provides a nonlinear optical crystal represented by $K_2Al_2B_2O_7$, and a wavelength conversion method using this nonlinear optical crystal, as well as an element and a wavelength conversion apparatus for use in the method.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention will become more readily appreciated and understood from the following detailed description of a preferred embodiment of the invention when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a cross-sectional view of the construction of a growing furnace used in the embodiment;
Fig. 2 is a view showing a result of X-ray diffraction of the structure of a KAB crystal according to the invention; and
Fig. 3 is a view showing another result of X-ray diffraction similar to that shown in Fig. 2.

DETAILED DESCRIPTION OF THE INVENTION

[0008] An embodiment of the invention will be described below with reference to a nonlinear optical crystal represented by $K_2Al_2B_2O_7$ (referred to simply as the KAB crystal) which is provided according to the invention. The KAB crystal has a structure in which K and Al are substituted for the respective Sr and Be sites of the publicly known SBBO crystal, i.e., $Sr_2Be_2B_2O_7$, although there is a difference in electric charge between both crystals.

[0009] The KAB crystal of this invention has a double refraction index of about 0.07 which is a nature approximately equal to that of the publicly known SBBO crystal. Accordingly, the KAB crystal is expected to generate vacuum ultraviolet light. The KAB crystal can easily be grown by a method such as a flux method.

[0010] The flux method is one kind of solution growth method, and is characterized by TSSG (Top Seeded Solution Growth), i.e., the process in which a seed crystal attached to a rotating shaft is immersed immediately below the surface of a solution to increase the degree of supersaturation by means of a decrease in temperature, thereby growing a crystal. In addition, the flux method is characterized by melting a flux and a source material.

[0011] Since the melting point of the KAB crystal is high, it is more preferable to grow the KAB crystal by the flux method (solution growth method) than by a melt method (melt growth method).

[0012] In this flux method, the crystal growth can be made far easier by using a flux such as lead oxide, sodium fluoride (NaF), cesium fluoride (CsF), lead fluoride or potassium chloride.

[0013] Accordingly, the KAB crystal of the invention is easy to grow and is superior in practical terms, and is extremely useful as a practical nonlinear optical crystal for generating vacuum ultraviolet light.

[0014] This crystal is actually utilized as an element for wavelength conversion or a wavelength conversion apparatus incorporated in this element.

[0015] Incidentally, it goes without saying that inevi-

table trace elements are allowed to be inevitably incorporated into the composition of the crystal of the invention by a growth process or a source material.

[0016] This invention will be described below in further detail with reference to an example.

EXAMPLE

[0017] Source materials having the following compositions were used to grow a crystal in the growing furnace shown in Fig. 1 by way of example:

K_2CO_3 (34 mol%),
Al_2O_3 (19 mol%),
B_2O_3 (45 mol%),
KCl (2 mol%).

[0018] The growing furnace shown in Fig. 1 has a construction like a cylindrical resistance heating furnace. In this furnace, its heater is vertically divided into five layers each of which can be independently controlled. A temperature program setting device capable of controlling temperature in units of a minimum of 0.1°C is used as a control part for the heater, and a quartz tube is disposed between the heater and a crucible so that a steep temperature gradient near the crucible is restrained. The crucible is made of platinum, and is arranged to move up and down by an elevating device lying at the bottom of the furnace, so that the crucible can be charged with a source material in a heated state. In addition, in order to correct a change in the temperature of the solution surface, a solution surface heater is disposed to prevent a decrease in temperature due to evaporation near the solution surface, thereby providing a temperature distribution optimum for crystal growth. At a temperature of about 1,000°C, the source material was melted in the atmospheric air, and was then cooled to grow into a microcrystal. The rate of temperature decrease was 0.2-0.3 °C/day, and the speed of rotation was 30 rpm (the direction of rotation was reversed at intervals of 3 minutes).

[0019] Through the above-described growth, a crystal of size about 3 mm was obtained.

[0020] The result of an analysis using plasma emission spectrometry (ICP) showed that this crystal had the composition of $K_2Al_2B_2O_7$. As is apparent from the result of four circle X-ray diffractometry shown in Figs. 2 and 3, it was confirmed that the structure of the obtained crystal was similar to that of the SBBO crystal but K and Al were 100% substituted for its Sr and Be sites, respectively.

[0021] In the evaluation of wavelength conversion characteristic (nonlinearity) of the crystal, when the crystal was illuminated with the fundamental light (wavelength 1,064 nm) of a Nd:YAG laser, the occurrence of light of second harmonic (532 nm) was confirmed.

[0022] In addition, when the double refraction index of this crystal was measured by an oil immersion method, it was confirmed that the value was 0.07 and was approximately equal to that of the SBBO crystal.

[0023] It is to be noted that since the shortest SHG wavelength of the prior art KBBF crystal is 185 nm or less and that of the prior art SBBO crystal is 200 nm or less, the KAB crystal of this invention can be phase-matched to approximately 200 nm. The absorption edge, of the KAB crystal was 180 nm or less.

[0024] In addition, the growth of the KAB crystal of this invention is far easy and far efficient compared to the case of SBBO and KBBF.

[0025] Incidentally, the Vickers hardness of the grown KAB crystal was about 300, and from the result of a water resistance test using immersion at room temperature, it was confirmed that the KAB crrystal did not dissolve even after the passage of ten days or more.

[0026] In accordance with the invention, there is provided a $K_2Al_2B_2O_7$ (KAB) crystal as a vacuum ultraviolet light generating nonlinear optical crystal which is easy to grow and of high practical use, and a wavelength conversion method using this crystal, as well as an element and a wavelength conversion apparatus for use in the method.

Claims

1. A nonlinear optical crystal represented by the formula: $K_2Al_2B_2O_7$.

2. A nonlinear optical crystal according to claim 1, which is solution growth by use of a flux.

3. A nonlinear optical crystal according to claim 2, where the flux is at least one kind selected from among lead oxide, sodium fluoride, cesium fluoride, lead fluoride or potassium chloride.

4. A wavelength conversion method of performing wavelength conversion by use of a nonlinear optical crystal according to any of claims 1 to 3.

5. A wavelength conversion element having a construction made of a nonlinear optical crystal according to any of claims 1 to 3.

6. A wavelength conversion apparatus having a construction in which a wavelength conversion element according to claim 5 is incorporated.

Fig. 1

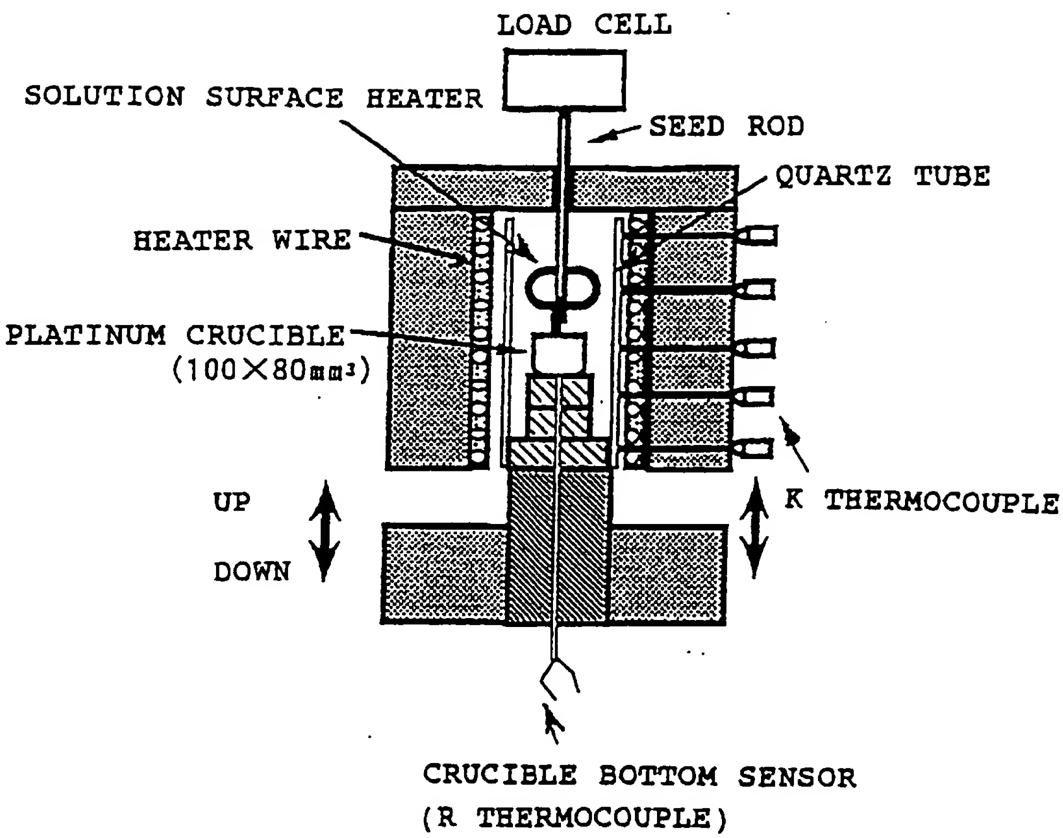

LOAD CELL
SOLUTION SURFACE HEATER
SEED ROD
QUARTZ TUBE
HEATER WIRE
PLATINUM CRUCIBLE
(100×80mm³)
UP
DOWN
K THERMOCOUPLE
CRUCIBLE BOTTOM SENSOR
(R THERMOCOUPLE)

Fig. 2

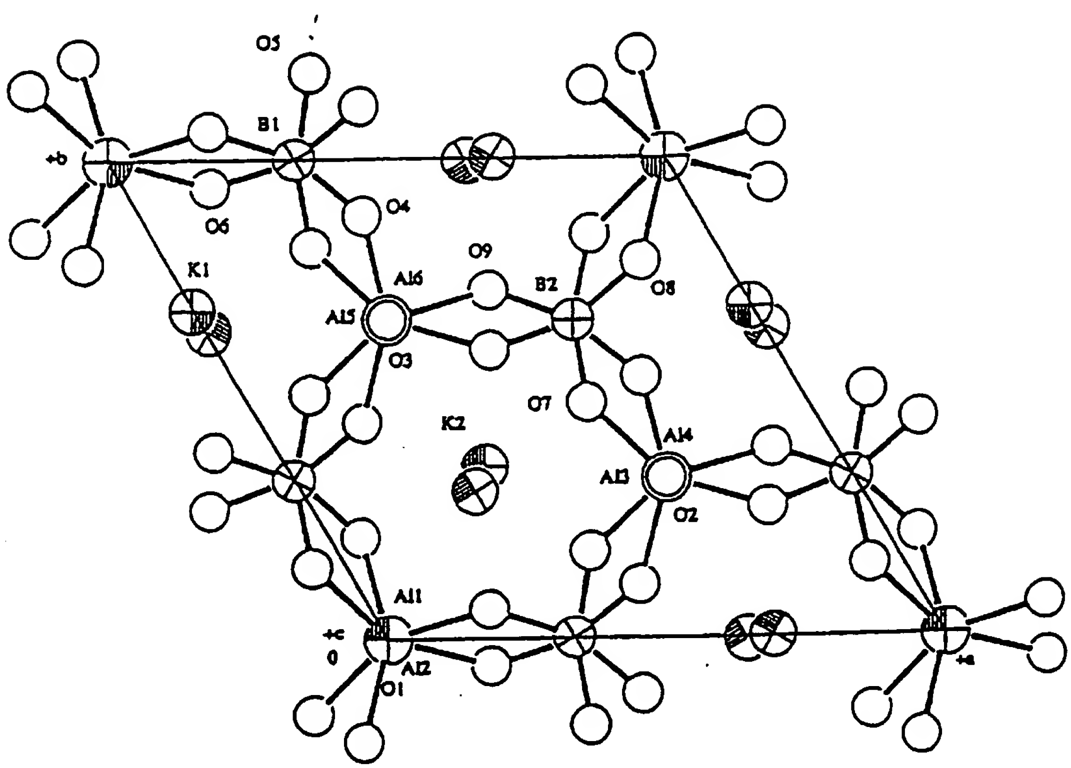
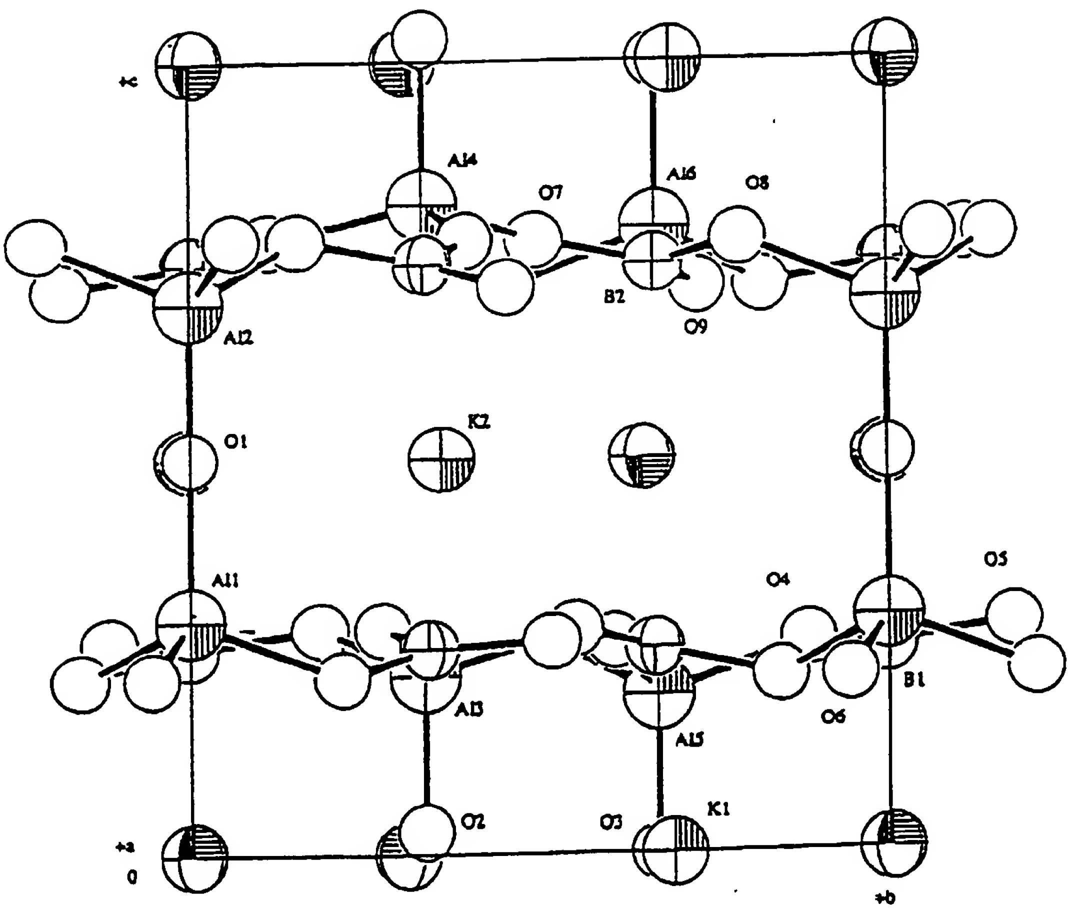


Fig. 3



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[6] G02F1/35

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[6] G02F1/35

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-1999
Kokai Jitsuyo Shinan Koho	1971-1999	Jitsuyo Shinan Toroku Koho	1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
CA (STN)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Proceedings of SPIE - The International Society for Optical Engineering, Vol. 3556, pp.156-161, (September, 1998) Zhang-Gui Hu et al.	1-6
P, X	Proceedings of SPIE - The International Society for Optical Engineering, Vol. 3556, pp.21-23, (September, 1998) Ning Ye et al.	1, 2, 4, 5, 6
P, X	Japanese Journal of Applied Physics, Part 2, Vol. 37, No. 10A, pp.L1093-L1094, (October, 1998) Zhang-Gui Hu et al.	1, 2, 4, 5, 6
A	Vestn. Leningr. Univ., Fiz., Khim., No. 3, pp.40-46, (1983), I.I. Kozhina et al.	1
P, A	Proceedings of SPIE - The International Society for Optical Engineering, Vol. 3556, pp.14-20, (September, 1998) Chuangtian Chen et al.	1, 2, 4, 5, 6
A	The Review of Laser Engineering, Vol. 26, No. 3, pp.215-219, (March, 1998) Yuusuke Mori, et al.	1-6

[x] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	Nature, Vol. 373, No. 6512, pp.322-324, (1995), Chuangtian Chen et al.	1, 2, 4, 5, 6
A	Journal of Applied Physics, Vol. 77, No. 6, pp.2268-2272, (1995) Chuangtian Chen et al.	1, 2, 4, 5, 6

Form PCT/ISA/210 (continuation of second sheet) (July 1992)